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Spatio-temporal Patterns of Intra-urban Land Use Change in Beijing, China Between 1984 and 2008

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Abstract: Urban internal structure is essential information for urban geography researchers and urban planners or managers. This research aims to examine the spatial structure changes of internal urban land use based on the interpreted datasets of 1984 and 2008. Spatio-temporal patterns of internal land use conversion and urban expansion are analyzed, and then dominant driving factors (e.g., social economy, population growth and urban planning) were identified. The results indicate that Beijing′s intra-urban layout has experienced tremendous adjustment from compact to disperse configure, otherwise its function objects have shifted from the major economic and industrial development before the 1990s to the combination with cultural, high-technological and inhabitable city at present. The dominant urban land use transformations include the relocation of industrial lands from core districts to suburban or other provinces, and the accelerating expansion of residential areas and green spaces for supplying the demand of housing and ecological protection. Although Beijing′s urban planning has experienced three major adjustments and improvement since the 1980s, its optimization of urban internal patterns still remains a challenge.
Keywords: intra-urban land use; urban planning; Geographic Information System (GIS); Beijing

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1 Introduction

Urbanization is a complex dynamic process and has resulted in irreversible environmental changes at local, regional and global scales. The negative effects become considerably complex with the influence of global environment change (Batty, 2008; Grimm *et al.*, 2008). IHDP (2005) seeks a better understanding of the interactions and feedbacks between urbanization and global environmental change through comparative cross-temporal and cross-spatial scale approaches. Research on the impacts of urbanization on climate, biodiversity, and hydrological systems from local to regional scales has attracted increasing attention (Grimm *et al.*, 2008; Montgomery, 2008). China as a representation of developing countries has experienced rapid urbanization since the reform and opening-up in the late 1970s. In 1984, Chinese central government made the decision of restructuring the economic system, promoting the reform of China's economic system from rural to an urban-centered stage. The transition from a centrally planned economy to a socialist market economy has brought considerable impacts on Chinese urban development (Gu and Shen, 2003). The city numbers, urban population and built-up areas increase from 300, 1.797×10^8, and 9 249 km^2 in 1984 to 655, 3.347×10^8, and 36 295 km^2 in 2008 (CUCSY, 2008). In particular, China has experienced tremendous land use change (LUCC) due to the rapid urbanization since the late 1980s (Liu *et al.*, 2005; Tian *et al.*, 2005; Deng *et al.*, 2008; Liu *et al.*, 2010).

Remote Sensing (RS) has become the primary data source for research related to urban land use change (Chilar and Jansen, 2001; Herold *et al.*, 2003). Many

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literatures have documented the rapid Chinese urban expansion and LUCC based on remote sensing data at national scale (Liu *et al*., 2005; Liu *et al*., 2010), regional scale such as Pearl (Zhujiang) River Delta (Seto *et al*., 2002; Seto and Kaufmann, 2003; Li and Yeh, 2004) and Beijing-Tianjin-Hebei metropolitan areas (Tan *et al*., 2005), and local scale such as the individual cities of Beijing, Shanghai, Guangzhou, Shijiazhuang and Changchun (Xiao *et al*., 2005; Kuang *et al*., 2005; Wu *et al*., 2006; Xie *et al*., 2007; Xu *et al*., 2007; Kuang *et al*., 2010). Most of the studies regarded urban area as a homogeneous entity for monitoring urban expansion. However, detail changes of urban internal structure reflecting urban socioeconomic attributes (e.g. commercial and industrial layout) and ecological functions (i.e. green open space) have not been fully investigated. Consequently, urban intrinsic evolution is poorly understood, partly due to the lack of spatially consistent datasets at a fine scale (Bounfour and Lambin, 1999; Xie *et al*., 2007). GIS provides a powerful tool for analyzing time series urban spatial datasets at fine scale by integrating remote sensing images and ancillary data (Paul and John, 2004; Kuang *et al*., 2010).

Beijing, the capital of China and a famous historical city of over 3000 years, and the second largest populated city in China, has experienced rapid urban expansion due to the population migration from rural to urban and fast economic development since social market economy in 1984. Due to its particular position in Chinese urban development, the urbanization issues of Beijing city have attracted much attention, mainly in three aspects: urban expansion, land use change monitoring and modeling (He *et al*., 2006; Wu *et al*., 2006; Xie *et al*., 2007; Zhao, 2010a); urban spatial structure, urban planning and sustainable management (Gu and Shen., 2003; Ding *et al*., 2005; Meng *et al*., 2008; Zhao *et al*., 2009a; Zhao, 2010b); and urban greening and environmental problems (Chen *et al*., 2005; Li *et al*., 2005; Zhang *et al*., 2007; Zhao *et al*., 2009b). However, those research has rarely examined the urban internal structure changes due to the dearth of fine-scale urban land use spatial datasets. This study aims to investigate intra-urban land use change for providing the specific knowledge for sustainable urban development. Specifically, this study detects and analyzes spatio-temporal characteristics of intra-urban land use change, including internal structure transformation and external expansion based on fine-scale intra-urban land use spatial datasets; identifies the main factors driving internal structure change; and provides suggestions for sustainable urban development based on the examination of existing problems in intra-urban spatial patterns.

2 Materials and Methods

2.1 Study area

Beijing (39°12′80″–41°12′50″ N, 115°12′50″–117°13′00″ E) is located in the North China Plain. The total area is 1.64×10^4 km^2. Beijing is recognized as the political, educational, and cultural center of China. The residential population and the Gross Domestic Product (GDP) of the city increased from 4.79×10^6 yuan and 2.17×10^{10} yuan in 1984 to 1.44×10^7 yuan and 1.05×10^{12} yuan in 2008. Annual urban fixed-asset investment and completed real estate area raised from 5.2×10^9 yuan and 8.19 km^2 to 3.55×10^{11} yuan and 36.22 km^2 (Beijing Municipal Statistical Bureau, 2008) at the same period. After the Summer Olympic Game was successfully held in Beijing in 2008, the average GDP exceeds 10 000 USD (United States dollar) in 2009.

To understand the detailed internal structure changes of Beijing, we selected the most intensively developed area as a study area. The population density of the study area was greater than 1000 persons/km^2 based on neighborhood of town spatial distribution from the 4th population census data. The total land area of this study area is 1336.39 km^2, accounting for 8.14% of whole Beijing area, with 64.67% of its population (Fig. 1).

2.2 Methods

Landsat TM images, SPOT images, aerial photographs, urban planning maps, and other auxiliary data were collected and geo-referenced using 1 : 10 000 topographic maps. Firstly, aerial photographs in 2008 were digitized as reference layers to extract urban main roads and basic road framework. After that, the minor roads were delimited in terms of various streets composed of urban main roads, and then, different urban blocks were divided based on this information. Land use type of each block was identified as a segmentation unit. In the meanwhile, attribute codes were assigned for segmentation units. The user-oriented intra-urban land use information was generated (Kuang *et al*., 2005; Liu *et al*., 2005; Liu *et*

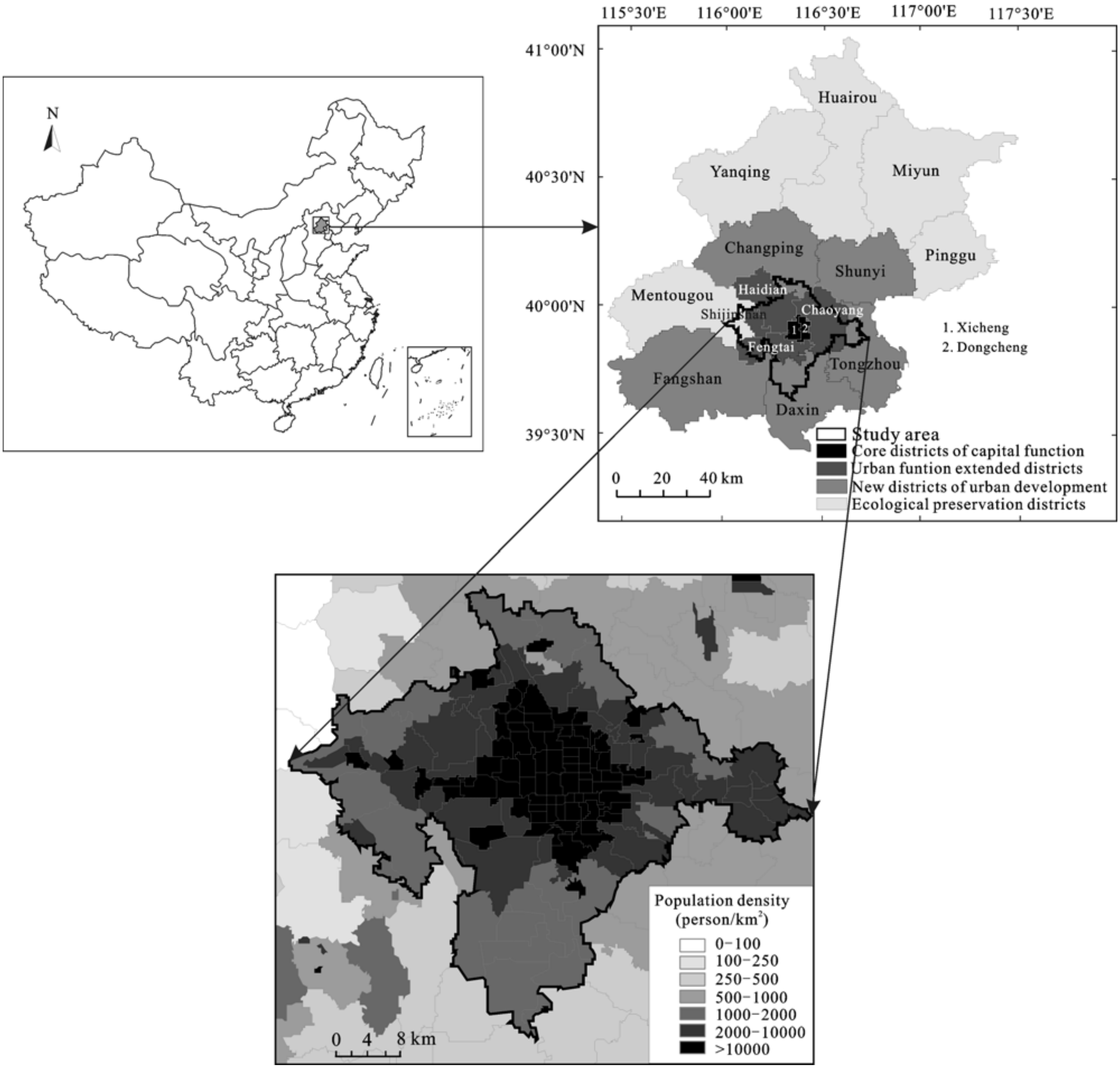


Fig. 1 Location of study area

al., 2010; Kuang *et al*., 2010; Kuang 2011). To accomplish digital reconstruction of urban land use information in 1984, we need first establish attribute tables. Urban land use types in 1984 were classified and classification codes were input into the field of the attribute tables to identity their change information. Furthermore, the intra-urban land use map of 1984 was developed by integrating internal urban classification map and Landsat TM images (Fig. 2), of which internal urban classification map was digitized from a mosaicked aerial photograph of 1984 (Institution of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences and National Planning Committee, 1990). The intra-urban land use map of 2008 was developed by digitizing a mosaicked aerial photograph of 2008 and SPOT5 images. The classification system (Table 1) was established according to the Anderson classification system (Anderson, 1976; Ikhuoria, 1987).

The classification accuracy was evaluated by field investigation. The total of 80 samples were collected and the detailed land use information was recorded, including GPS locations, photos from different orientations, land type, building stories, construction time and so on. The overall accuracy was 91% with highest accuracy 94% for green space and lowest accuracy of 88% for commercial land.

Change patterns of intra-urban spatial structure were explored based on urban land use datasets between 1984 and 2008. The two urban land use maps were overlaid to generate urban spatial structure change induced by intra-urban transformation and urban expansion. The spatio-temporal characteristics of intra-urban transformation and urban expansion were further analyzed, based on the statistical data from the change data. The social economy, population growth and urban planning impacts on spatial structure were examined, too.

3 Results

3.1 Changes of intra-urban land use

Urban land in the study area was increased from 330.63 km^2 in 1984 to 1123.92 km^2 in 2008 with annual expansion area of 33.05 km^2. Urban land accounted for only 24.74% in 1984, but it increased to 84.10% in 2008 due to fast urban growth since market economy. Crop

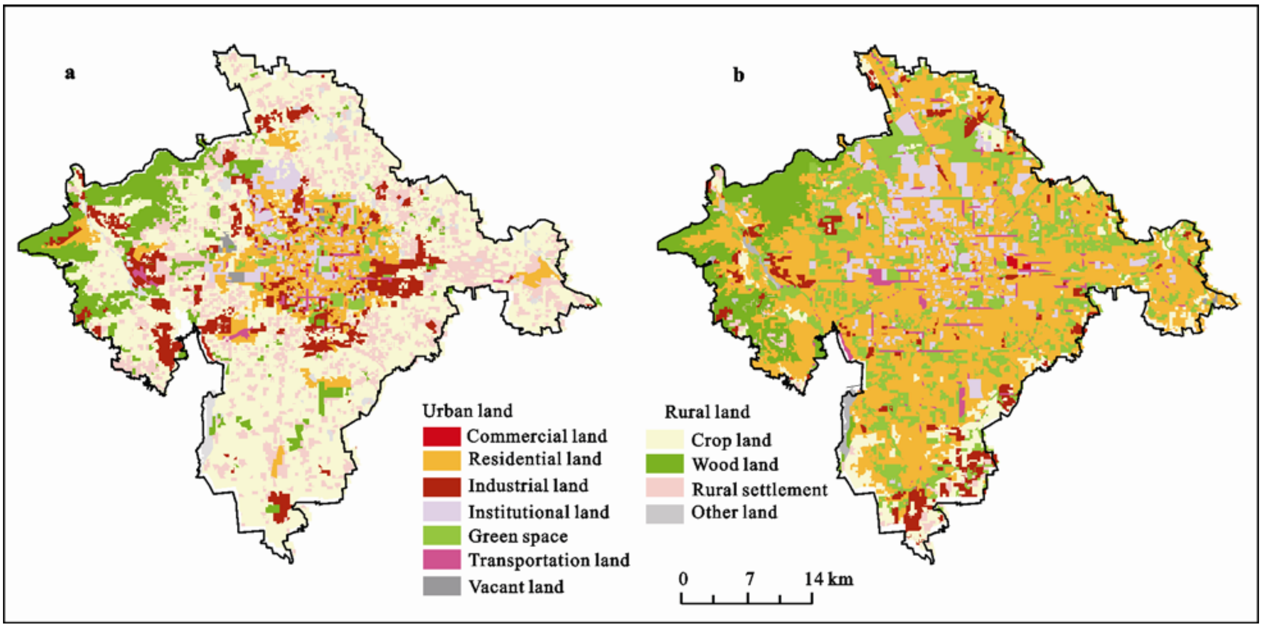


Fig. 2 Intra-urban land use maps of study area in 1984 (a) and 2008 (b)

Table 1 Urban land use classification scheme

Type		Class
Urban land	Commercial Land (CO)	Commercial center Service center
	Residential Land (RE)	Independent residential land Mixed residential land
	Industrial land (ID)	General industrial land Industrial park
	Institutional land (IS)	Educational (Schools and colleges) Institutes Government and establishments
	Green space (GR)	Green space Water body
	Transportation land (TR)	Roadway Utilities
	Vacant land (VA)	Bare land in urban area
Rural land	Crop land (CL)	Land supplied for vegetables Paddy land Dry land
	Wood land (WL)	Forest Orchard
	Rural settlements (RL)	Rural villages
	Other land (OL)	Other land in rural areas

land in countryside had the highest percentage of 50.27% in 1984. In contrast, the highest portion was residential area, which accounted for 52.64% in 2008, indicating that the study area had experienced rapid transformation from natural landscape to man-made construction.

According to the changes of urban function characteristics, the commercial land grew 4.64 times, mainly in the Xidan and Wangfujin commercial and service agglomerations of the Tiananmen Square zygomorphous areas. Residential land had the highest growing rate of 23.79 km^2 /year to provide more residential space for growing population. Industrial land decreased by 50.58 km^2 due to the relocation of heavy industries to outskirt. Institutional land for education and research, and government was increased with an annual rate of 1.81 km^2. Green land and water body had tremendous expansion with 13.54 times for improving urban landscape and ecological functions. Transportation land increased due to the urban expansion. Vacant land in urban fringe was filled in, and its area was decreased by 4.19 km^2 (Table 2). During the period between 1984 and 2008, residential land and open green space hold high growing rate and became the most prominent change in urban internal characteristics to meet demands for housing and urban ecological protection.

3.2 Intra-urban structure transformation

Beijing experienced significant intra-urban spatial changes from 1984 to 2008, including internal urban land transformation and urban expansion outward. According to internal urban land conversion matrix, the most significant change was the transformation from industrial to residential lands (Table 3). At the same time, a large amount of industrial land was transferred to institutional land and green space. These changes happened at urban-rural fringe in the urban function extended districts in 1984 (Fig. 3a). In order to promote economical growth, a large number of heavy industries were set up in the outskirts of Beijing during the 1970s and the early 1980s. Therefore, some industrial zones were formed gradually, including cotton textile industrial zone in eastern suburb, electronic industrial zone in northeastern suburb, engine and chemical plant industrial zone in southeastern suburb, and metallurgy and engine heavy industrial development in western suburb. With fast urban expansion outward, the industrial zones were surrounded in the core urban districts. As a result, urban environment has been greatly degraded due to the pollution from industrial zones. Since the 1980s, urban master planning of Beijing regulated to relocate these heavy industries from inner-city to outskirts. This policy resulted in lots of industries clearing away from the center of city.

Another important conversion was the transformation from residential land to institutional land and green space. To optimize the urban spatial structure, Beijing′s government implemented the reconstruction of old infrastructure. The capacious institutional land and green space were constructed in inner-city to improve urban environment. In this stage, vacant land of 2.99 km^2 was in-filled with residential land, which was distributed

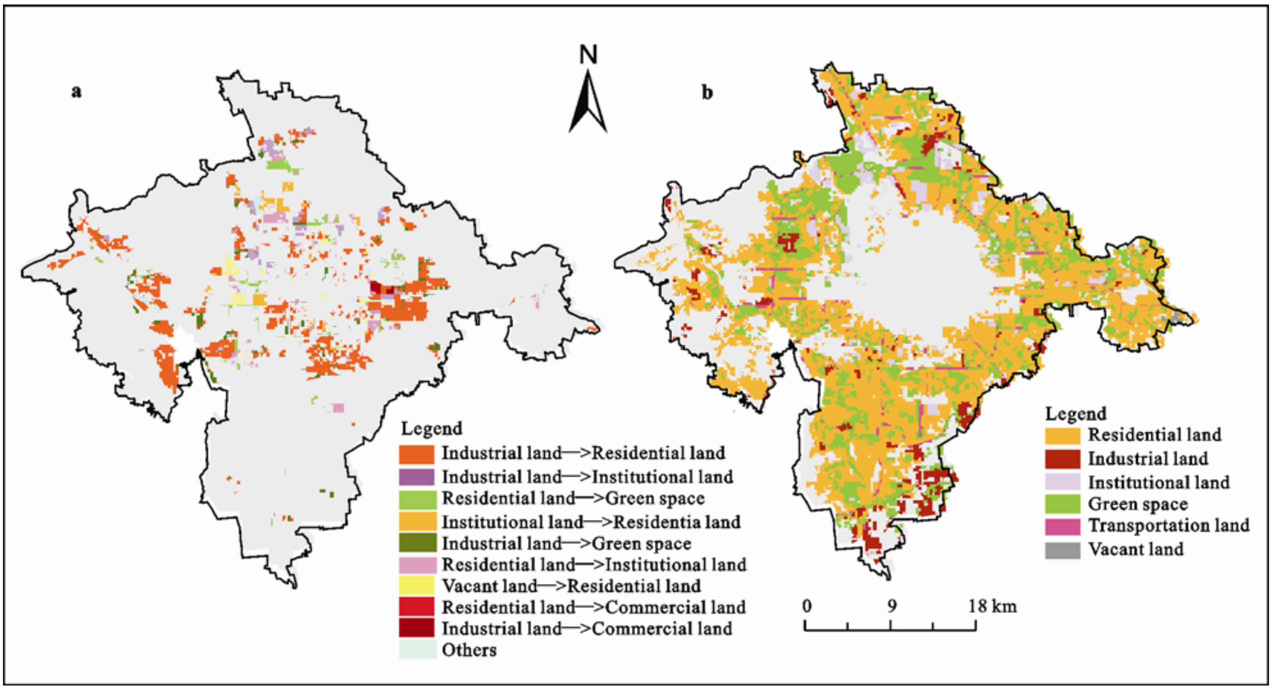
Table 2 Urban land area and percentage in 1984 and 2008

Type	1984		2008	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Commercial land (CO)	0.45	0.03	2.09	0.16
Residential land (RE)	132.57	9.92	703.49	52.64
Industrial land (ID)	110.21	8.25	59.63	4.46
Institutional land (IS)	47.77	3.57	91.32	6.83
Green space (GR)	16.79	1.26	227.35	17.01
Transportation land (TR)	17.46	1.31	38.85	2.91
Vacant land (VA)	5.38	0.40	1.19	0.09
Crop land (CL)	671.81	50.27	86.78	6.49
Wood land (WL)	101.60	7.60	94.11	7.04
Rural settlements (RL)	184.97	13.84	10.74	0.80
Other land (OL)	47.38	3.55	20.84	1.56
Total	1336.39	100.00	1336.39	100.00

Table 3 Intra-urban land transformation area in Beijing between 1984 and 2008 (km^2)

Type	CO	RE	ID	IS	GR	TR
RE	0.19	0.00	0.13	7.25	5.43	1.12
ID	1.42	78.06	0.00	9.31	4.75	2.79
IS	0.03	5.12	0	0	2.31	0.15
GR	0.00	0.57	0.12	0.48	0.00	0.00
TR	0.00	2.17	1.69	0.21	0.54	0.00
VA	0.00	2.99	0.07	0	0.03	2.28
Total	1.64	88.91	2.01	17.26	13.06	6.34

Notes: Commercial land (CO); Residential land (RE); Industrial land (ID); Institutional land (IS); Green space (GR); Transportation land (TR); Vacant land (VA)



a. intra-urban transformation; b. urban expansion type

Fig. 3 Intra-urban land use change in Beijing between 1984 and 2008

mostly in the western suburb in 1984, along with urban sprawl. The internal urban land transformation was closely related to urban planning policies.

3.3 Analysis of urban expansion characteristics

Urban expansion characteristics were detected by using high-precision data from 1984 to 2008. Total area of urban expansion was 793.43 km^2 with encroaching crop land and rural settlements in this period (Table 4). Residential land expansion accounted for 64.54 % of the total expansion area. Crop land of 336.05 km^2 and rural settlements of 138.23 km^2 on urban fringe were converted to residential areas (Table 4). Green land had the second fastest growth rate, with the area of 198.73 km^2 which were mainly located between the fifth and the sixth-ring roads (Fig. 3b). Industrial land increased by 43.74 km^2 in the urban fringe of Beijing due to the construction of new industrial parks and the relocations of industries from inner-city to suburb. Institutional and transportation land expansion dispersed outward to a large extent. The urban expansion was influenced by fast population and economic growth since the market economy beginning in 1984.

3.4 Intra-urban structural evolution modes

Intra-urban structural evolution modes were generalized based on spatial patterns of urban land use change from 1984 to 2008 (Fig. 4). They reflected the radial concen-

Table 4 Urban expansion area from different urban land types between 1984 and 2008 (km^2)

Type	RE	ID	IS	GR	TR	VA	Total
CL	336.05	35.25	21.78	155.24	12.99	1.00	562.31
WL	14.12	1.61	2.62	15.09	0.56	0.00	34.01
RL	138.23	4.88	7.31	18.10	4.33	0.18	173.01
OL	7.80	2.01	2.19	10.31	1.78	0.01	24.09
Total	496.20	43.74	33.90	198.73	19.67	1.18	793.43

Notes: Residential land (RE); Industrial land (ID); Institutional land (IS); Green space (GR); Transportation land(TR); Vacant land(VA); Crop land (CL); Wood land (WL); Rural settlements (RL); Other land (OL)

tric patterns which were dated back to the geo-political structure of city developing history from the Ming and the Qing dynasties. City wall and ring road were established to form a concentric regular structure around the Forbidden (Zijin in Chinese) City. The Forbidden City as the center of the ancient city of Beijing had strong military and political function, which constructed the foundation of urban evolution model.

Since the early 1980s, spatial patterns of Beijing have manifested the capital political function and kept change until now. The preponderant resident and other mixed areas were distributed from the center to the 3rd ring road and expanded to the 6th ring road as its function became stronger. Commerce and education were primary functions in 1984. Commercial centers were developed and formed important functional multi-nuclei (e.g. Xidan, Wangfujin) in 2008. Technology and science function became stronger due to convergence of universities and research institutions, for example, the Zhongguancun high-technology park which is located on the northwestern of city, was established in 2008.

Because many heavy industries were moved out to outskirts, four powerful industrial centers in the city fringe were weakened or disappeared since 1984 by enforcement of the urban planning and management. Beijing has expanded with ten peripheral constellations to mitigate the great population pressure. To prevent urban sprawling growth, greenbelt was formed gradually around the 5th ring road between core urban areas and the peripheral constellations. Urban radial ring road system is the important factor to influence the urban structure model. The 4th, 5th and 6th ring roads constructed in 2001, 2003 and 2009 have played important roles in shaping the urban structural models.

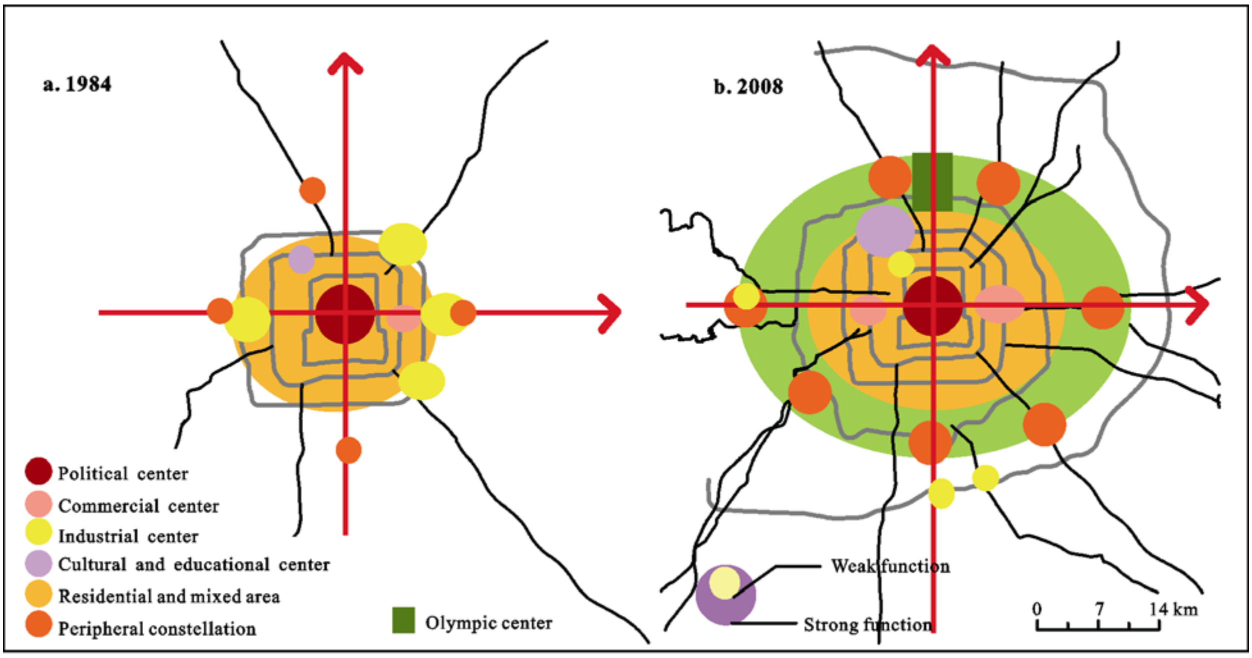


Fig. 4 Intra-urban spatial structural evolution modes in Beijing

3.5 Social-economy and population factors

Social-economic development and urban population growth determine the demand of urban land use. Since the market economy has transited successfully in 1984, Beijing has experienced the fastest urbanization process from 1984 to 2008. Urban residential population increased 3 times from 4.79×10^6 to 14.39×10^6, while GDP increased by 96.40 times in this period (Fig. 5). The intra-urban structure change with a total urban expansion of 793.43 km^2 and residential land increase of 570.92 km^2 were detected. Economic growth promoted the increase of urban fixed-asset investment, which would provide the requirement for real estate construction (Fig. 6). The real estate was prosperous to meet housing demand of population immigration from rural to urban. In this period, annual completed real estate

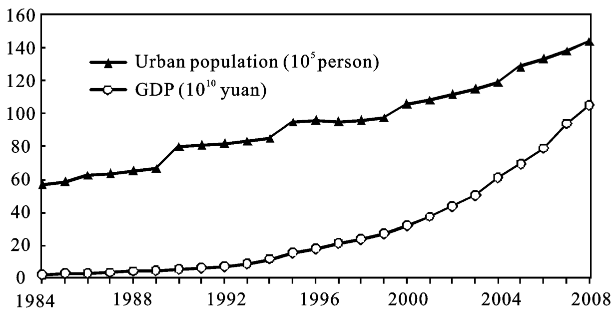


Fig. 5 Trends of population and GDP between 1984 and 2008 in Beijing

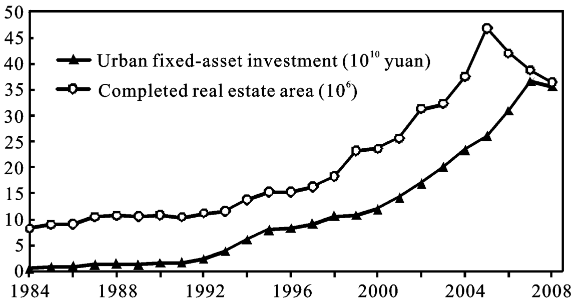


Fig. 6 Urban fixed-asset investment growth and real estate area between 1984 and 2008 in Beijing

area raised 8.9 times. The analysis showed that social-economy and population growth were the most important driving factors in affecting urban growth.

3.6 Urban planning factors

Beijing has formulated and modified urban planning policies for 6 times since the early 1950s, to meet urban development requirement. These policies had great impacts on the urban structure change (Table 5). In the late 1950s, urban planning of Beijing was implemented to establish a modern industrial base and conceived the satellite towns around urban fringe. Therefore, a large number of industrial zones such as the capital steel industrial base was constructed in northeastern and eastern outskirts. However, the satellite towns were not formed completely during this period. Urban functions have had

Table 5 Urban planning schemes and their effects on urban structure in Beijing

Period	Planning name	Planning summary and layout schemes	Effects on urban structure
1953–1954	Planning amendment summary to re-construct and extend Beijing	Political center was set up in heartland of city. Industrial agglomeration zones and great agro-bases were built in the four suburbs. Northwest suburbs were cultural and educational zone. Road systems overlay chessboard and radical ring forms	It influenced the single-center formation with radical ring shape. Industrial agglomeration groups were built around urban fringe.
1957–1958	Preliminary schemes of urban building master planning in Beijing	The spatial layout of disperse convergences composed of core urban area and its affiliated forty-satellite towns. It encouraged to develop industries in distant suburbs and controlled strictly the construction in core urban area	It promoted urban homocentric expansion. Industrial layout was not controlled effectively in core urban area.
1982	Urban building master planning schemes of Beijing	It continued disperse convergences layout, but adjusted periphery structure became the ten independent-function fringe groups with 2 km width segregating greenbelt between urban core area and periphery groups	This planning played significant roles in shaping current urban patterns. Multi-groups were formed with industry relocation and greenbelt construction
1993	Urban master planning of Beijing (from 1991 to 2010)	It confirmed that urban development transformed strategically along southern and eastern axes, especially along Beijing-Tianjin-Tangshan highway	It promoted periphery groups development with low density sprawl along traffic axes
2004	Urban master planning of Beijing (from 2004 to 2020)	Urban structure of two axes from traditional south to north and from west to east along Chang'an Avenue, two belts along east and west belts with sub-centers of suburb, nuclear function zones (e.g. Zhongguancun high-technical park, Olympic center, CBD and so on) with axial, extended and radical forms	It improved urban independent function with nuclear function zones. Periphery groups had fast growth and agglomerated with urban core area, but they induced the urban sprawl with low density and greenbelts were threatened by housing demand growth.

Source: Beijing Municipal Institute of City planning & Design, 2006 great change since the reform policy in 1978. Urban function transition from economic center to political and cultural center was emphasized in urban planning of 1982. Intra-urban structure was adjusted under the influence of this guideline. Heavy industries located in the inner-city were replaced with high-technical industries. The new urban master planning of 1993 and 2004 promoted the axial, extended and radical periphery group′s development, resulting in external expansion around urban fringe. Therefore, urban planning played an important role in shaping urban spatial patterns, especially urban master planning had profound influence on intra-urban structure transformations, such as inner-city renewal and greenbelt construction.

4 Discussion

Urban spatial layout of Beijing was related closely with its political and historical status. Socialist market economy with inflow of rural migrants played an important role in shaping the urban spatial structure, especially external expansion (Gu and Shen, 2003). Although urban structure was improved due to urban master planning, this study indicates that urban spatial layout still has irrational aspects, for example, urban built-up lands (e.g., residential land) concentrate on central districts owing to its strong pulling function. Although urban comprehensive greening plans at the regional, city and neighborhood levels were established (Li *et al*, 2005), green ecological buffer belts designed by Li *et al*. (2005) have not been in action to prevent urban sprawl, and greenbelt was not enough to separate the peripheral constellations from the core area. The transition from planning-oriented to market-oriented and unimplemented urban planning were responsible for the irrational layouts in this period (Ding *et al*., 2005).

Urban land of the study area increased 3.4 times between 1984 and 2008. Beijing has experienced urban low-density sprawl with homocentric expansion around ring-road system driven by multiple factors such as the globalizing market economy and land reform, significant events such as Olympic games in 2008 since the economic reform of 1978 (Xie *et al*., 2007). Water shortage was becoming a serious issue to constrain urban development in Beijing (Chen *et al*., 2005; He *et al*., 2006). Our analysis indicated that Beijing was not enough compact compared with 1984. As a result, residential and green land growth aggravated the water shortage because more water resources were demanded for supplying drinking and ecological requirements.

According to urban master planning (2004–2020), Beijing′s resident population will be no more than 16×10^6 in 2020. Due to mono-centric strong core area function, it is difficult to form multi-center periphery groups to alleviate the central city pressure. We suggest urban planning emphasize to develop one or two sub-centers. At the same time potential urban functional transformation should be strengthened through implementing the preferred developing policies. Municipal administrators must take measures to prevent greenbelt engrossed. The ecological corridors around urban fringe should play an important role in protecting urban ecology and promoting urban smart growth.

5 Conclusions

Spatial information of intra-urban structure is indispensable to better understand urban intrinsic evolution for supporting urban planning and decision-making. The fine-scale time series urban land use data reflect the urban detailed internal structure, but they are difficult to obtain owing to the limited remote sensing data source. Intra-urban land types (e.g., commercial and residential land) are not always distinguished from each other successfully although high spatial resolution remotely sensed images are applied. Based on the urban internal spatial data of two periods which were extracted by the integration of multi-source data, this study successfully examined the spatio-temporal patterns of intra-urban land use changes and identified the dominant factors influencing the urban functional and structural transformation.

Our study indicated that Beijing not only had undergone rapid external expansion driven by dual economical growth and population growth since the market economy in 1984, but also experienced significant internal land transformations influenced by urban planning regulation. The relocation of heavy industries plays an important role in improving urban environmental conditions between 1984 and 2008. To optimize the urban spatial structure, the capacious institutional land and green space were layout in urban core area. Urban internal structure of Beijing has been transited from economy-oriented to multi-functional city in order to meet residential and ecological protection requirements.

Beijing, as the Chinese capital, is experiencing fast urbanization under globalization. Beijing-Tianjin-Tangshan urban metropolitan areas are conceived and the relative preferential policies are proposed. Beijing is undertaking tremendous pressure from everlasting sprawl and its environmental problems. Although Beijing′s urban planning has experienced significant adjustment, urban planning is still facing a challenge. Some irrational layouts have been found in our research. The greenbelt construction is not enough to separate the core urban area from periphery groups. Many peripheral constellations under influence of urban master planning are not completely formed to bear the relatively independent function constellation. The planner should select one or two from many peripheral constellations as sub-center to resolve the biscuit sprawl around ring-road system. The measures to optimize the internal urban structure should be taken by linking politicians with scientists.

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